CLAIMS

1. A method of reducing nitrogen oxides, including NO, in an exhaust stream also comprising oxygen, carbon monoxide and hydrocarbons at a temperature above about 150°C, said method comprising:

passing air through a non-thermal plasma reactor to generate an ozone containing plasma and adding said plasma to said exhaust stream for oxidation of NO to NO_2;

adding ethanol to said exhaust stream, separately from the addition of said plasma, for the reduction of said nitrogen oxides; and

thereafter contacting said exhaust stream with a dual bed reduction catalyst comprising NaY zeolite and/or BaY zeolite in the first bed and CuY zeolite in the second bed to reduce said nitrogen oxides to N_2.

2. The method of reducing nitrogen oxides as recited in claim 1 in which ethanol is added to said exhaust stream downstream of the addition of said ozone containing plasma.

3. The method of reducing nitrogen oxides as recited in claim 1 wherein said plasma reactor is a tubular vessel having a reactor space for flow-through passage of air, said plasma reactor comprising a high voltage electrode disposed within said reactor space and a ground electrode helically coiled around said tubular vessel, thereby providing intertwined helical passive and active electric fields for the generation of said ozone containing plasma.

4. The method of reducing nitrogen oxides as recited in claim 1 in which the flow of said exhaust gas through said first bed is at a space velocity that is higher than the space velocity of the flow of said exhaust gas through said second bed.

5. The method of reducing nitrogen oxides as recited in claim 1 comprising adding ethanol to said exhaust stream as ethanol vapor in an air stream.

6. The method of reducing nitrogen oxides as recited in claim 5 comprising passing an air stream through a solution of ethanol to produce ethanol vapor in said air stream.

7. The method of reducing nitrogen oxides as recited in claim 6 wherein said ethanol is dissolved in gasoline and ethanol comprises at least about 85% by volume of the solution.

8. The method of reducing nitrogen oxides as recited in claim 6 wherein said ethanol is dissolved in diesel fuel, where said ethanol constitutes approximately 1-15% by volume of the solution.

9. The method of reducing nitrogen oxides as recited in claim 1 comprising operating said plasma reactor at a plasma energy density in the range of 0 to 20 J/L as a function of catalyst temperatures in the range of 150°C to 400°C, said plasma energy density being zero, or reduced to zero, at catalyst temperatures of 350°C or higher.

10. The method of reducing nitrogen oxides as recited in claim 1 in which ethanol is added to said exhaust stream at a molar ratio of ethanol to nitrogen oxides ($EtOH/NO_x$) in the range of 5 to 25 as function of catalyst temperatures in the range of 150°C to 400°C.

11. A method of reducing nitrogen oxides, NO_x including NO, in a diesel engine exhaust stream also comprising oxygen, carbon monoxide

and hydrocarbons at a temperature above about 150°C, said method comprising:

(a) passing said exhaust stream into contact with an oxidation catalyst to oxidize said carbon monoxide and hydrocarbons;

(b) passing air through a non-thermal plasma reactor to generate an ozone containing plasma and adding said plasma into said exhaust stream for oxidation of NO to NO_2, the energy applied to said plasma reactor being inversely proportional to the temperature of the reduction catalyst at temperatures in the range of about 150°C to 400°C with said energy being reduced to zero at temperatures of about 350°C and higher;

(c) adding ethanol to said exhaust stream for the reduction of said nitrogen oxides, the amount of said ethanol being increased in proportion to the reduction catalyst temperature; and thereafter

(d) flowing said exhaust stream through a dual-bed catalytic reduction reactor, said reactor comprising a first bed consisting essentially of barium and/or sodium Y zeolite catalyst and a second bed consisting essentially of copper Y zeolite catalyst, where the volume of said first bed is larger than the volume of said second bed.

12. The method as recited in claim 11 wherein said plasma reactor is a tubular vessel having a reactor space therein for flow-through passage therein, said plasma reactor comprising a high voltage electrode disposed within said reactor space and a ground electrode helically coiled around said tubular vessel, thereby providing intertwined helical passive and active electric fields for the generation of said ozone containing plasma.

13. The method as recited in claim 11 comprising evaporating ethanol from E-diesel and adding the ethanol to said exhaust stream as a vapor in an air stream.

14. The method of reducing nitrogen oxides as recited in claim 11 in which ethanol is added to said exhaust stream at a molar ratio of ethanol to nitrogen oxides ($EtOH/NO_x$) in the range of 5 to 25 as function of catalyst temperatures in the range of 150°C to 400°C.